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Measurement of the $K\beta_2/K\beta_1$ ratio in heliumlike krypton

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Abstract.
We report the measurement of the $K\beta_2/K\beta_1$ ratio of He-like krypton using the SuperEBIT electron beam ion trap at the Lawrence Livermore National Laboratory. The energy of these lines are about 15 keV, which is twice as high as the energy of such lines measured before. A comparison with theoretical predictions shows poor agreement, confirming the trend uncovered earlier where the measured result is considerably larger than predicted.

1. Introduction

In a previous measurement of the intensity ratio of the $1s3p\ ^1P_3 \rightarrow 1s^2\ ^1S_0$ intercombination line, commonly labeled $K\beta_2$, to that of the $1s3p\ ^1P_3 \rightarrow 1s^2\ ^1S_0$ resonance line, commonly labeled $K\beta_1$, it was shown that theoretical predictions underestimated the measured values [1]. This study was carried out for ions with intermediate atomic number $12 \leq Z \leq 26$. The discrepancy with theory was largest for the line ratios from the ions with lowest atomic number, i.e., for magnesium, and diminished for the ratios from the ions with highest atomic number under study, i.e., iron. The measurements were performed on the EBIT-II electron beam ion trap [2] at the Lawrence Livermore National Laboratory. Most of these measurements were carried near the threshold energy for excitation of the $K\beta$ transitions.

Among several reasons for the discrepancy, the effects of polarization of the emitted X-ray lines were mentioned as a possible cause, as the unidirectional beam in an electron beam ion trap creates linearly polarized light. This effect was amplified because the x rays were detected with crystal spectrometers, which have different reflectivities for the two polarization components.

In this paper, we report the measurement of the $K\beta_2/K\beta_1$ ratio of He-like krypton using an x-ray microcalorimeter [3]. This instrument is insensitive to the polarization of the incident photons. The present measurement extends the previous study to an ion with considerably higher atomic number. In fact, the x-ray energy of the $K\beta$ lines of krypton is about twice that of the corresponding lines in iron.

2. Experiment

The measurement was performed on the SuperEBIT electron beam ion trap at the Lawrence Livermore National Laboratory. Like in the earlier measurements [1], the photons were detected in the plane perpendicular to the electron beam. Although the microcalorimeter is an energy dispersive device whose quantum efficiency is independent of the polarization degree of the x-ray photons, the linear polarization of the photons given off by the trapped ions affects the measured ratio through the anisotropy factor. However, such a dependence on the degree of polarization is much weaker than the strong effect on a measurement made with a crystal spectrometer.

The measurements were carried out with an electron beam current of about 160 mA and at a beam energy of 86 keV. The spectrum, which was measured with the microcalorimeter over a period of 28 hours and collected during five run days, is shown in Fig. 1. Data from 20 pixels were added together.

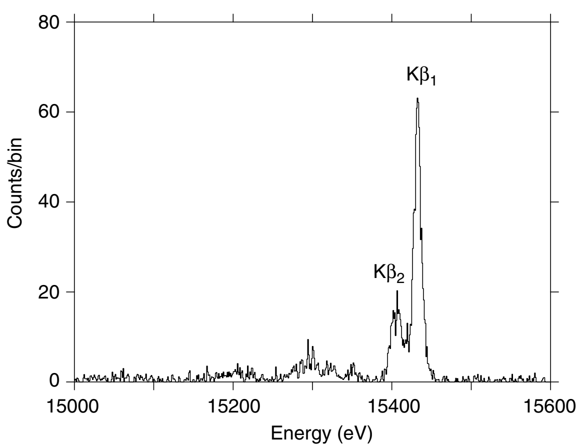

Figure 1. X-ray emission of the n=3 $\rightarrow$ n=1 transitions of heliumlike krypton measured with the microcalorimeter on SuperEBIT.

The measured ratio is $I_{K\beta_2}/I_{K\beta_2} = 0.37 \pm 0.06$. The uncertainty is about thrice that solely due to counting statistics. The reason is the that the $K\beta_2$ peak is somewhat ill formed, which introduces an amount of arbitrariness in fitting the lines and thus an uncertainty that goes beyond statistical uncertainty. The less than perfect line shape is probably caused by the low count rate of the experiment, which makes proper adding of individual pixels difficult.

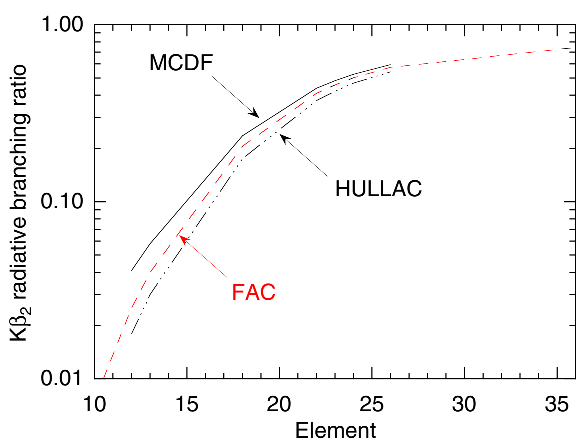

Figure 2. Comparison of the radiative branching ratios of the $1s3p\ ^3P_1$ level for producing the $K\beta_2$ transition calculated by our FAC calculations (shown in red) with values from MCDF and HULLAC calculations reported in [1].

3. Comparison with theory

We have carried out calculations of the atomic data needed for predicting the $I_{K\beta_2}/I_{K\beta_2}$ ratio using the Flexible Atomic Code (FAC) [4]. All levels up to $n = 6$ were included in the collisional radiative model. The calculations include the radiative branching ratio to the $1s^2\ ^1S_0$ level from the $1s2p\ ^3P_1$ level. The results for heliumlike ions between oxygen and krypton are shown in Fig. 2, where they are compared to values calculated before [1] using two different codes. The agreement with the earlier calculations is excellent.

We have also calculated the radiative branching ratio of the decay of the $1s3p\ ^1P_1$ level. That ratio remains nearly constant from oxygen (β_r=0.95) to krypton (β_r=0.93).

We have also calculated the linear x-ray polarization of the krypton $K\beta_1$ and $K\beta_2$ lines as a function of the electron-impact energy. The results are shown in Fig. 3. At the beam energy of our experiment the polarization is $P = 0.270$ for $K\beta_1$ and $P = 0.258$ for $K\beta_2$. In other words, there is no difference in the respective values of polarization, and no adjustments need to be made to account for differences in polarization and angular anisotropies.

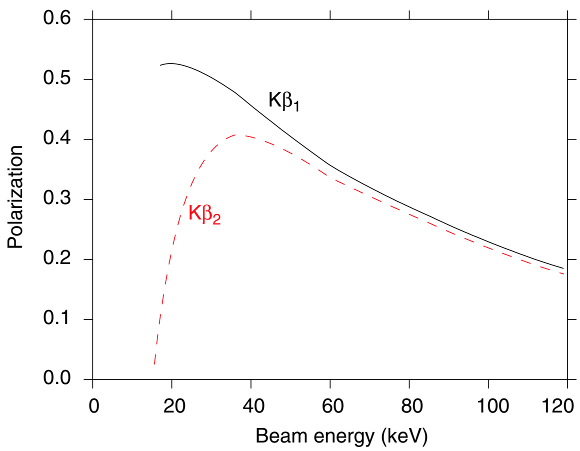

Figure 3. Calculated values of the linear polarization of $K\beta_1$ and $K\beta_2$ as a function of electron beam energy.

We used FAC to calculate $I_{K\beta_2}/I_{K\beta_2}$ as a function of beam energy, as shown in Fig. 4. The ratio varies near threshold and approaches a constant value at high energy. It assumes a value of 0.22 at 86 keV. This values is about 40% less than measured, as indicated in Fig. 4.

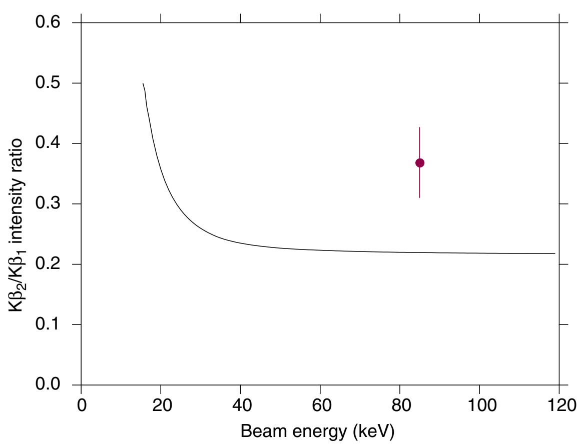

Figure 4. Comparison of calculated and measured values for the intensity ratio of $K\beta_1$ and $K\beta_2$.

4. Discussion

The measured intensity ratio is significantly larger than predicted. This has been found before in the study of heliumlike ions of magnesium through iron [1]. Our measurement, however, was carried not close to the threshold energy for excitation, as was done in the earlier study, but it was carried out at very high electron energy. in fact, the measurement was carried at a beam energy close to six threshold units. Unfortunately, this means that Kr^{35+} ions were present in the trap during the measurement. Both radiative electron capture from the interaction with the electron beam and charge exchange with neutral background ions may add to the population of the $1s3p\ ^3P_1$ level and thus enhance the $K\beta_2$ line preferentially compared to the $K\beta_1$ line.

Modeling of this enhancement is beyond the scope of the present study, as there is no definitive diagnostic that can quantify the amount of charge exchange occuring in the trap.

Future measurements will need to study the line ratio near threshold, i.e., close to 15,500 eV where no Kr^{35+} ions are produced. Such a measurement was not possible with our setup, as the count rate in the $K\beta$ lines near a beam energy of 15.5 keV would have been too weak to allow for a meaningful addition of the spectra recorded by individual pixels of the microcalorimeter. However, we have now developed new techniques to sum very weak signals [5, 6]. Moreover, the utilization of our EBIT-I facility, where we can achieve a higher beam current at the required beam energy than on SuperEBIT, will increase the amount of signal collected in the future.

Acknowledgments
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